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(11) **EP 1 449 264 B1**

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention
of the grant of the patent:
09.08.2006 Bulletin 2006/32

(51) Int Cl.:
C09K 11/64 (2006.01)

(21) Application number: **03750612.8**

(86) International application number:
PCT/EP2003/010599

(22) Date of filing: **23.09.2003**

(87) International publication number:
WO 2004/030109 (08.04.2004 Gazette 2004/15)

(54) **PHOTOLUMINESCENT MATERIAL FOR LIGHT EMITTING DIODES, AND LIGHT EMITTING DIODE**
FOTOLUMINESZIERENDE STOFFE FÜR LEUCHTDIODEN, UND LEUCHTDIODE
MATERIAU PHOTOLUMINESCENT POUR DIODES ELECTROLUMINESCENTES, ET DIODE
ELECTROLUMINESCENTE

(84) Designated Contracting States:
**AT BE BG CH CY CZ DE DK EE ES FI FR GB GR
HU IE IT LI LU MC NL PT RO SE SI SK TR**

(30) Priority: **24.09.2002 EP 02021172**

(43) Date of publication of application:
25.08.2004 Bulletin 2004/35

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EP 1 449 264 B1

Description**Technical Field**

- 5 [0001] This invention relates to a photoluminescent material which is excitable in the UV-blue part of the spectral region, and more particularly, but not exclusively to a phosphor for light sources, especially for Light Emitting Diodes (LED). The phosphor belongs to the class of rare-earth activated silicon oxynitrides.

Background Art

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[0002] So far white LEDs were realized by combining a blue-emitting diode with a yellow emitting phosphor. Such a combination has a poor color rendition, which, however, can be improved significantly by using a red-green-blue system (RGB). Such a system uses for example a red and blue emitter in combination with a green-emitting aluminate phosphor, like $\text{SrAl}_2\text{O}_4:\text{Eu}$ or $\text{BaAl}_2\text{O}_4:\text{Eu}$, with the possible addition of Mn to Eu, whose emission maximum is around 520 nm, see US-A 6 278 135. However, the position of the excitation and emission bands of these aluminates is not optimum. They have to be excited by short UV in the range of 330 to 400 nm.

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[0003] On the other hand, some phosphors derived from the class of MSiON are known; see e.g. "On new rare-earth doped M-Si-Al-O-N materials" by van Krevel, TU Eindhoven 2000, ISBN 90-386-2711-4, Chapter 6. They are doped with Tb. Emission is achieved upon excitation by 365 nm or 254 nm.

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[0004] US-A 6 255 670 discloses a phosphor $\text{A}_2\text{DSi}_2\text{O}_7:\text{Eu}^{2+}$ where A is at least one of Ba, Sr, Ca and D is Mg and Zn.

[0005] EP-A 1 193 306 discloses a phosphor $\text{mM}^1\text{O} \times \text{nM}^2\text{O} \times 2\text{M}^3\text{O}_2$ wherein M^1 is at least one metal selected from Ca, Sr and Ba, M^2 is at least one metal selected from Mg and Zn, M^3 is at least one metal selected from Si and Ge, and m and n satisfy $0.5 \leq m \leq 3.5$ and $0.5 \leq n \leq 2.5$, respectively with an activator being selected from at least one of Eu and Mn.

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[0006] EP-A 1 104 799 discloses a red emitting phosphor with a host lattice of the nitridosilicate type $\text{M}_x\text{Si}_y\text{N}_z:\text{Eu}$, wherein M is at least one of Ca, Sr, Ba and with $z = 2/3x + 4/3y$.

[0007] US-A 2002/043926 discloses a light emitting device with an Ca-Al-Si-O-N oxynitride activated with Eu^{2+} .

Disclosure of the Invention

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[0008] It is an object of the present invention to provide a new photoluminescent material. A further object is to provide a phosphor with a fine-tuned green emission which can be efficiently excited by UV/blue radiation. A further object is to provide a phosphor for use in an illumination device with at least one LED as light source, the LED emitting primary radiation in the range from 380 to 470 nm, this radiation being partially or completely converted into longer-wavelength radiation by such phosphors which are exposed to the primary radiation of the LED. A further object is to provide an illumination device which emits white light and in particular has a high color rendering. A further object is to provide a high-efficiency illumination device like a LED device which absorbs well in the range from 380 to 470 nm and is easy to produce.

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[0009] These objects are achieved by the characterizing features of claim 1 and 9, respectively. Particularly advantageous configurations are given in the dependent claims 2-8, respectively, 10-12.

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[0010] The conversion is achieved at least with the aid of a phosphor which originates from the class of the Eu- or Eu, Mn-coactivated silicone oxynitrides. In more detail, a novel phosphor material is created by doping $\text{MSi}_2\text{O}_2\text{N}_2$ (M = Ca, Sr, Ba) host lattices with Eu ions. The obtained phosphors show high chemical and thermal stability.

[0011] More extended fine tuning of all relevant properties can be obtained by partial replacement up to 40%, the certain percent proportion given as x, of group (SiN) by (AlO), resulting in a general composition given by $\text{MSi}_{2-x}\text{Al}_x\text{O}_{2+x}\text{N}_{2-x}$, the preferred range is 1 to 15% ($x = 0.01$ to 0.15).

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[0012] Preferably, the metal M is Ca or at least mainly Ca with minor additions of Ba and/or Sr for a green-emitting material which can be efficiently excited with blue radiation. The incorporation of nitrogen increases the degree of covalent bonding and ligand-field splitting. As a consequence this leads to a shift of excitation and emission bands to longer wavelengths compared to oxide lattices. The obtained phosphors show high chemical and thermal stability.

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[0013] More extended fine tuning of all relevant properties can be obtained by use of a cation M which is achieved by combining several of said M metals, by inclusion of Zn as part of cation M, preferably up to 5 - 40 mol-% of M, and/or at least partial replacement of Si by Ge. The amount of Eu doped to cation M is a partial replacement of between 0.1 and 25 %, preferably between 2 and 15% of M. In addition, under the assumption of a given amount of Eu, further doping with Mn for fine-tuning of relevant properties is possible with an preferred amount of at most 50% of the given Eu doping.

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[0014] Since these materials can convert UV-blue radiation into green light due to low-energy excitation bands, they can be applied for example in white light sources (e.g. lamps), especially based on primarily blue-emitting LEDs (typically based on GaN or InGaN with emission around 430 to 470 nm) combined with a red-emitting phosphor. A suitable red-emitting phosphor is a Eu-doped silicon nitride material, like $\text{M}_2\text{Si}_5\text{N}_8$ (M = Ca, Sr, Ba), see for example WO 01/40403.

Also application for colored light sources is possible.

Brief Description of the Drawings

[0015] In the text which follows, the invention is explained in more detail with reference to a plurality of exemplary embodiments. In the drawings:

Figure 1 shows a semiconductor component (LED) which serves as light source for white light, with casting resin (Figure 1a) and without casting resin (Figure 1b);

Figure 2 shows an illumination device with phosphors in accordance with the present invention;

Figure 3 to 5 show the emission spectra and reflection spectra of phosphors in accordance with the present invention.

Best Mode for Carrying Out the Invention

[0016] By way of example, a structure similar to that used in WO 01/40403 is described for use in a white LED together with an InGaN chip. The structure of such a light source for white light is specifically shown in Figure 1a. The light source is based on a semiconductor component (chip 1) of type InGaN with a peak emission wavelength of 400 nm, having a first and a second electrical connection 2,3, which is embedded in an opaque base housing 8 in the region of a recess 9. One of the connections 3 is connected to the chip 1 via a bonding wire 4. The recess has a wall 7 which serves as reflector for the blue primary radiation of the chip 1. The recess 9 is filled with a potting compound 5 which contains a silicone casting resin (or epoxy casting resin) as its main constituents (pref. at least 80 % by weight) and further comprises phosphor pigments 6 (pref. less than 15% by weight). There are also further small amounts of, inter alia, methyl ether and Aerosil. The phosphor pigments are a mixture of three pigments which emit blue, green and red light with the green phosphor being in accordance with the invention.

[0017] Fig.1b shows an embodiment of a light source with a semiconductor component 10 in which the conversion into white light is effected by means of phosphor conversion layers 16 which are applied directly to the individual chip. On top of a substrate 11 there are a contact layer 12, a mirror 13, a LED chip 14, a filter 15 and a phosphor layer 16, which is excited by the primary radiation of the LED, and converts it into visible long-wave radiation. This structural unit is surrounded by a plastic lens 17. Only the upper contact 18 of the two ohmic contacts is illustrated. Primary UV radiation of the LED is around 400 nm and secondary radiation is emitted by a first phosphor in accordance with the invention using $\text{BaSi}_2\text{O}_2\text{N}_2\text{:Eu}$ emitting around 500 nm and by a second phosphor using a Nitridosilicate emitting orange-red.

[0018] Figure 2 shows an illumination device 20. It comprises a common support 21, to which a cubical outer housing 22 is adhesively bonded. Its upper side is provided with a common cover 23. The cubical housing has cutouts in which individual semiconductor components 24 are accommodated. They are blue emitting light-emitting diodes with a peak emission of around 450 to 470 nm. The conversion into white light takes place by means of conversion layers 25 which are arranged on all the surfaces which are accessible to the blue radiation. These include the inner surfaces of the side walls of the housing, of the cover and of the support. The conversion layers 25 consist of phosphors which emit in the red spectral region, and in the green spectral region using a phosphor according to the invention and mixing up together with the non-absorbed part of the primary radiation blue primary into white light.

[0019] Eu_2O_3 (with purity 99.99%), BaCO_3 (with purity > 99.0%), SrCO_3 (with purity > 99.0%), CaCO_3 (with purity > 99.0%), SiO_2 and Si_3N_4 were used as commercially available starting materials for the production of the new inventive phosphors. The raw materials were homogeneously wet-mixed in the appropriate amounts by a planetary ball mill for 4-5 hours in isopropanol. After mixing the mixture was dried in a stove and ground in an agate mortar. Subsequently, the powders were fired in molybdenum crucibles at 1100-1400 °C under a reducing nitrogen/hydrogen atmosphere in a horizontal tube furnace. After firing, the materials were characterized by powder X-ray diffraction (copper K-alpha line).

[0020] All samples show efficient photoluminescence under UV-blue excitation with emission maxima in the blue-green (in case of $\text{M} = \text{Ba}$), green ($\text{M} = \text{Ca}$) or yellow-green ($\text{M} = \text{Sr}$). Typical examples of emission and excitation spectra can be seen in Fig. 3 ($\text{M} = \text{Ca}$), Fig. 4 ($\text{M} = \text{Sr}$) and Fig. 5 ($\text{M} = \text{Ba}$). For $\text{CaSi}_2\text{O}_2\text{N}_2\text{:Eu}$ a green-emitting phosphor (560 nm peak emission) is obtained, which can be efficiently excited in the blue part of the spectrum (excitation maximum at about 440 nm). By using a mixed compound with $\text{M} = (\text{Ba}, \text{Sr})$ and varying the proportion of Ba and Sr, the emission can be shifted in the range 500-570 nm, while the top of the excitation band can be shifted from 400 nm up to 430 nm. The observed shift to higher wavelengths is ascribed to a center of gravity of the Eu 5d band at lower energy and a stronger ligand-field splitting of the Eu 5d band. Additional manipulation can be achieved by at least partial replacement (for example up to 15 mol-%) of (SiN) by (AlO), resulting in a preferred structure $\text{MSi}_{2-x}\text{O}_{2+x}\text{Al}_x\text{N}_{2-x}\text{:Eu}$ (e.g. $x = 0,15$).

[0021] Since these materials can convert UV-blue radiation into green light due to low-energy excitation bands, they can be applied in white light sources, for example based on primarily blue-emitting LEDs (typically GaN or InGaN)

combined with a red-emitting phosphor.

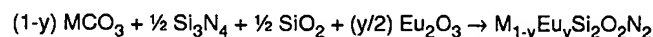
[0022] Additional fine tuning can be achieved by incorporation of Zn as an addition to cation M, preferably not more than 30%, and at least partial replacement of Si by Ge, preferably not more than 25 %.

Table 1

Raw materials	Grade
MCO ₃ (M = Ca, Sr, Ba)	99.0%
SiO ₂	Aerosil OX50
γ-Al ₂ O ₃	> 99.995
Si ₃ N ₄	β content: 23.3%, O ~ 0.7%
Eu ₂ O ₃	99.99%

[0023] In the following the synthesis procedures are given. Possible starting materials are shown in table 1.

[0024] All the oxynitride phosphors can be synthesized according to the following reaction equation:



with (M = Ca, Sr, Ba). For example $y = 0, 1$.

[0025] The powder mixture is fired for several hours in Mo crucibles at 1100-1400 °C in a reducing atmosphere of mainly N₂ with small amounts of H₂ (10%) in horizontal tube furnaces.

[0026] With the atomic radius decreasing from Ba to Ca it was found that the replacement of (SiN)⁺ by (AlO)⁺ by this reaction became easier.

[0027] Figure 3 shows a typical emission/excitation spectra of CaSi₂O₂N₂:Eu.

[0028] Figure 4 shows a typical emission/excitation spectra of SrSi₂O₂N₂:Eu.

[0029] Figure 5 shows a typical emission/excitation spectra of BaSi₂O₂N₂:Eu.

[0030] Doping with Eu was 10% of cation M in all embodiments.

[0031] The peak emission for M = Ca was around 560 nm, and for M = Sr it was around 570 nm, and for M = Ba it was around 500 nm.

Claims

1. Photoluminescent material, especially a phosphor for Light Emitting Diode-applications, which is excitable in the UV-blue region from 380 to 470 nm, **characterized by** a Eu-doped host lattice with general composition M (SG)_{2-x}Al_xO_{2-x}N_{2-x}, wherein M is at least one of an alkaline earth metal chosen from the group Ca, Sr, Ba alone or in combination with Zn; SG is chosen from Si alone or in combination with Ge, and with a proportion of Eu from 0,1 to 25% of M and with x being at most 0,4, preferably x being at most 0,15.
2. UV-blue excitable photoluminescent material according to claim 1, wherein the general composition is MSi₂O₂N₂.
3. UV-blue excitable photoluminescent material according to claim 1, wherein M is Calcium in order to achieve green emission.
4. UV-blue excitable photoluminescent material according to claim 1, wherein M is a mixture of at least two of the metals Ca, Sr, Ba.
5. UV-blue excitable photoluminescent material according to claim 1, wherein M comprises up to 30 % Zn.
6. UV-blue excitable photoluminescent material according to claim 1, wherein SG is a combination of Si and Ge with the Ge proportion being up to 25 %.
7. UV-blue excitable photoluminescent material according to claim 1, wherein the host material is further doped with Mn, the amount of Mn being at most up to 50% of the Eu doping.

8. UV-blue excitable photoluminescent material according to claim 1, wherein the general composition is given by $MSi_{2-x}Al_xO_{2+x}N_{2-x}$, and SiN is partially replaced by AlO, wherein the replacement is at most 15 %.
9. Light source (20) with a UV-blue excitable photoluminescent material according to one of the preceding claims.
10. Light source according to claim 9, wherein the primary emitted light is blue and the UV-blue excitable photoluminescent material according to claims 1-8 is combined with other phosphors, especially a red emitting phosphor, in order to convert part of the primary emitted light into secondary emitted light of longer wavelength resulting in emitting white light.
11. Light source according to claim 9, wherein the primary emitted light is UV and the photoluminescent materials according to claims 1-8 are combined with other phosphors, especially a red and a blue emitting phosphor, in order to convert the primary emitted light into secondary emitted light of longer wavelength resulting in emitting white light.
12. Light source according to claim 9, wherein the light source is an illuminating device with at least one Light Emitting Diode.

Patentansprüche

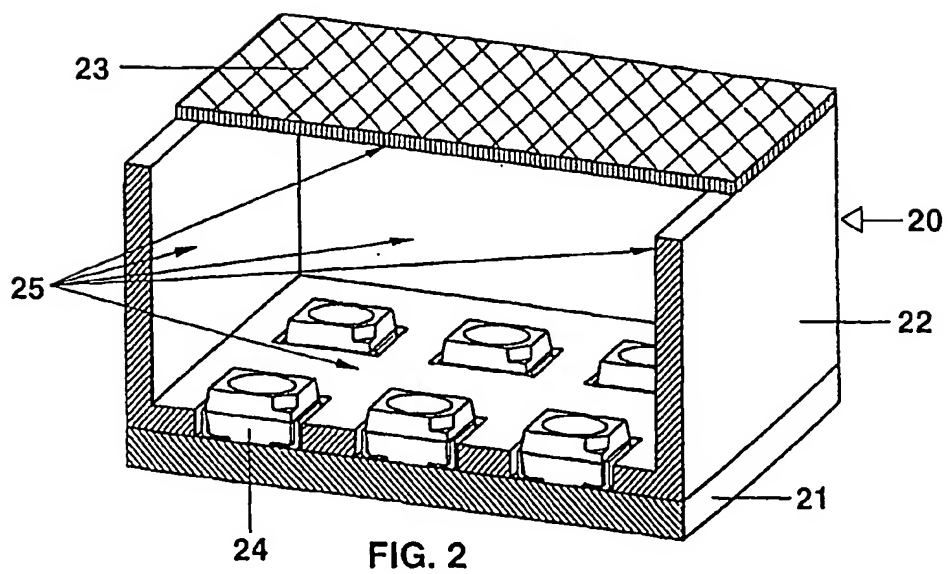
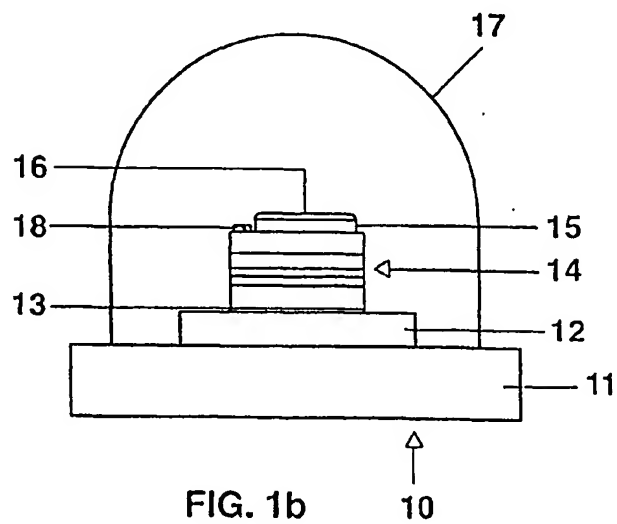
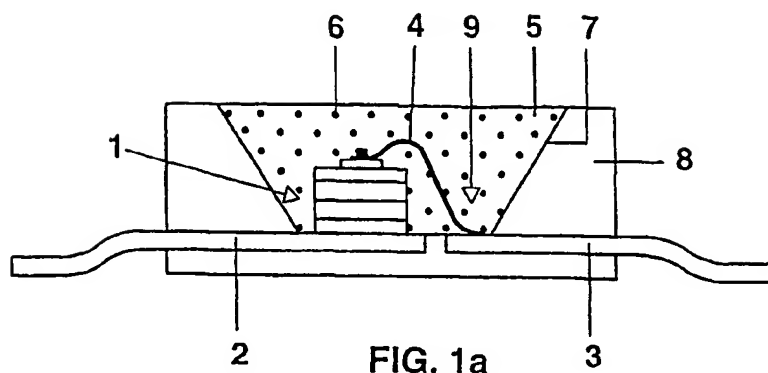
1. Photolumineszierendes Material, insbesondere ein Leuchtstoff für Leuchtdiodenanwendungen, das in dem UV-Blau-Bereich von 380 bis 470 nm angeregt werden kann, **gekennzeichnet durch** ein Eu-dotiertes Wirtsgitter mit allgemeiner Zusammensetzung $M(SG)_{2-x}Al_xO_{2+x}N_{2-x}$, wobei M mindestens eines eines Erdalkalimetalls ausgewählt aus der Gruppe Ca, Sr, Ba alleine oder in Kombination mit Zn ist; SG ausgewählt ist unter Si alleine oder in Kombination mit Ge, und mit einem Anteil von Eu von 0,1 bis 25% von M, und wobei x höchstens 0,4, bevorzugt höchstens 0,15 beträgt.
2. UV-Blau-anregbares photolumineszierendes Material nach Anspruch 1, wobei die allgemeine Zusammensetzung $MSi_2O_2N_2$ ist.
3. UV-Blau-anregbares photolumineszierendes Material nach Anspruch 1, wobei M Calcium ist, um eine grüne Emission zu erreichen.
4. UV-Blau-anregbares photolumineszierendes Material nach Anspruch 1, wobei M eine Mischung von mindestens zwei der Metalle Ca, Sr, Ba ist.
5. UV-Blau-anregbares photolumineszierendes Material nach Anspruch 1, wobei M bis zu 30% Zn umfaßt.
6. UV-Blau-anregbares photolumineszierendes Material nach Anspruch 1, wobei SG eine Kombination aus Si und Ge ist, wobei der Ge-Anteil bis zu 25% beträgt.
7. UV-Blau-anregbares photolumineszierendes Material nach Anspruch 1, wobei das Wirtsmaterial weiter mit Mn dotiert ist, wobei die Menge an Mn höchstens bis zu 50% der Eu-Dotierung beträgt.
8. UV-Blau-anregbares photolumineszierendes Material nach Anspruch 1, wobei die allgemeine Zusammensetzung gegeben ist durch $MSi_{2-x}Al_xO_{2+x}N_{2-x}$ und SiN teilweise durch AlO ersetzt wird, wobei die Ersetzung höchstens 15% beträgt.
9. Lichtquelle (20) mit UV-Blau-anregbarem photolumineszierendem Material nach einem der vorhergehenden Ansprüche.
10. Lichtquelle nach Anspruch 9, wobei das primäre emittierte Licht Blau ist und das UV-Blau-anregbare photolumineszierende Material nach den Ansprüchen 1-8 mit anderen Leuchtstoffen kombiniert ist, insbesondere einem rotemittierendem Leuchtstoff, um Teil des primären emittierten Lichts in sekundäres emittiertes Licht längerer Wellenlänge umzuwandeln, was zum Emittieren von weißem Licht führt.
11. Lichtquelle nach Anspruch 9, wobei das primäre emittierte Licht UV ist und die photolumineszierenden Materialien nach den Ansprüchen 1-8 mit anderen Leuchtstoffen kombiniert sind, insbesondere einem rot- und einem blaue-

mittierenden Leuchtstoff, um das primäre emittierte Licht in sekundäres emittiertes Licht längerer Wellenlänge umzuwandeln, was zum Emittieren von weißem Licht führt.

12. Lichtquelle nach Anspruch 9, wobei die Lichtquelle eine Beleuchtungseinrichtung mit mindestens einer Leuchtdiode ist.

Revendications

1. Matière photoluminescente, en particulier substance luminescente pour des applications de diodes émettant de la lumière, qui peut être excitée dans la région UV bleu de 380 à 470 nm, **caractérisée par** un réseau d'hôtes dopés par Eu ayant la composition générale $M(SG)_{2-x}Al_xO_{2+x}N_{2-x}$, dans laquelle M est au moins l'un d'un métal alcalino-terreux choisi dans le groupe Ca, Sr, Ba, seuls ou en combinaison avec Zn ; SG est choisi parmi Si seul ou en combinaison avec Ge et avec une proportion de Eu représentant de 0,1 à 25 % de M, et x étant au plus de 0,4, et de préférence x étant au plus de 0,15.
2. Matière photoluminescente pouvant être excitée dans l'UV bleu suivant la revendication 1, dans laquelle la composition générale est $MSi_2O_2N_2$.
3. Matière photoluminescente pouvant être excitée dans l'UV bleu suivant la revendication 1, dans laquelle M est calcium afin de finir une émission dans le vert.
4. Matière photoluminescente pouvant être excitée dans l'UV bleu suivant la revendication 1, dans laquelle M est un mélange d'au moins deux des métaux Ca, Sr, Ba.
5. Matière photoluminescente pouvant être excitée dans l'UV bleu suivant la revendication 1, dans laquelle M comprend jusqu'à 30 % de Zn.
6. Matière photoluminescente pouvant être excitée dans l'UV bleu suivant la revendication 1, dans laquelle SG est une combinaison de Si et de Ge, la proportion de Ge allant jusqu'à 25 %.
7. Matière photoluminescente pouvant être excitée dans l'UV bleu suivant la revendication 1, dans laquelle la matière hôte est dopée en outre par Mn, la quantité de Mn allant au plus jusqu'à 50 % du dopage par Eu.
8. Matière photoluminescente pouvant être excitée dans l'UV bleu suivant la revendication 1, dans laquelle la composition générale est donnée par $MSi_{2-x}Al_xO_{2+x}N_{2-x}$, et SiN est remplacé en partie par AlO, le remplacement étant d'au plus 15 %.
9. Source (20) lumineuse ayant une matière photoluminescente pouvant être excitée dans l'UV bleu suivant l'une des revendications précédentes.
10. Source lumineuse suivant la revendication 9, dans laquelle la lumière émise de façon primaire est bleue et la matière photoluminescente pouvant être excitée dans l'UV bleu suivant les revendications 1 à 8 est combinée à d'autres substances luminescentes, en particulier à une substance luminescente émettant dans le rouge, afin de transformer une partie de la lumière émise de façon primaire en de la lumière émise de façon secondaire de plus grande longueur d'onde, ce qui donne une émission de lumière blanche.
11. Source lumineuse suivant la revendication 9, dans laquelle la lumière émise de façon primaire est de l'UV et les matières photoluminescentes suivant les revendications 1 à 8 sont combinées à d'autres substances luminescentes, en particulier à une substance luminescente émettant dans le rouge et dans le bleu, afin de transformer la lumière émise de façon primaire en de la lumière émise de façon secondaire de plus grande longueur d'onde, ce qui donne une émission de lumière blanche.
12. Source lumineuse suivant la revendication 9, dans laquelle la source lumineuse est un dispositif d'éclairage ayant au moins une diode émettant de la lumière.



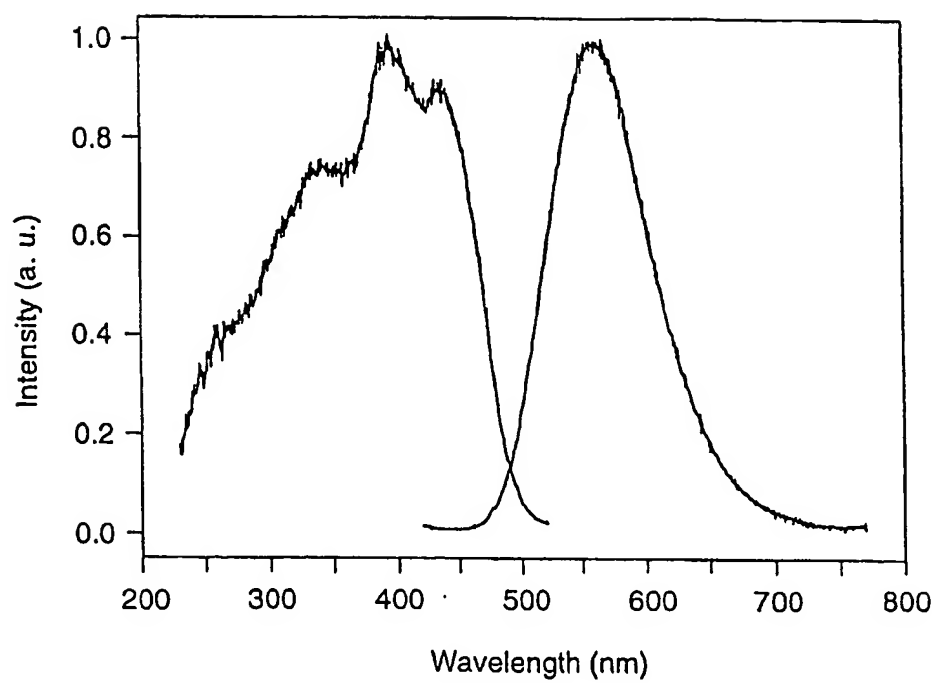


FIG. 3

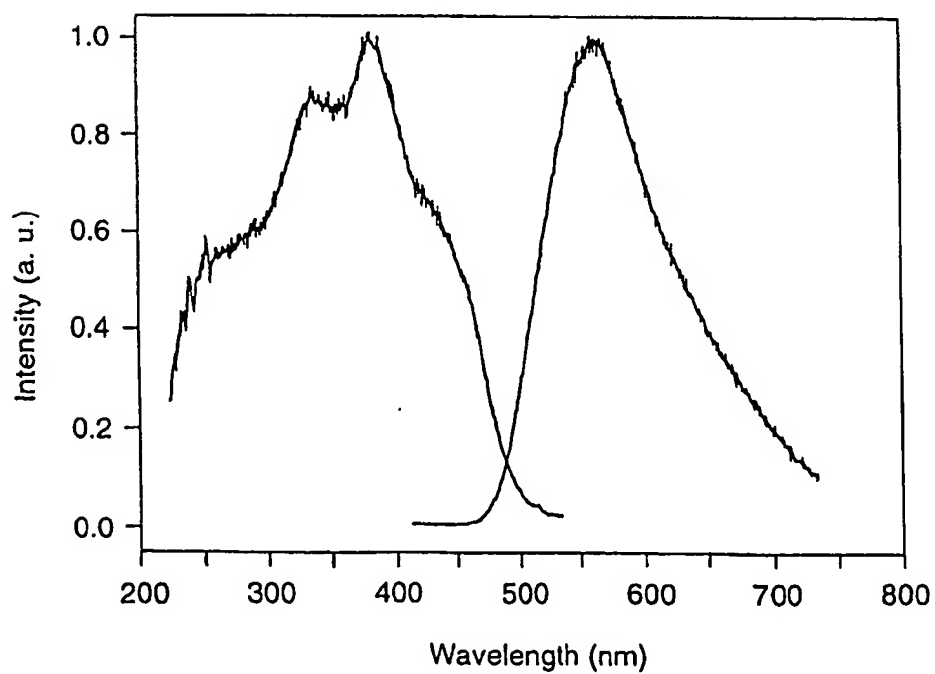


FIG. 4

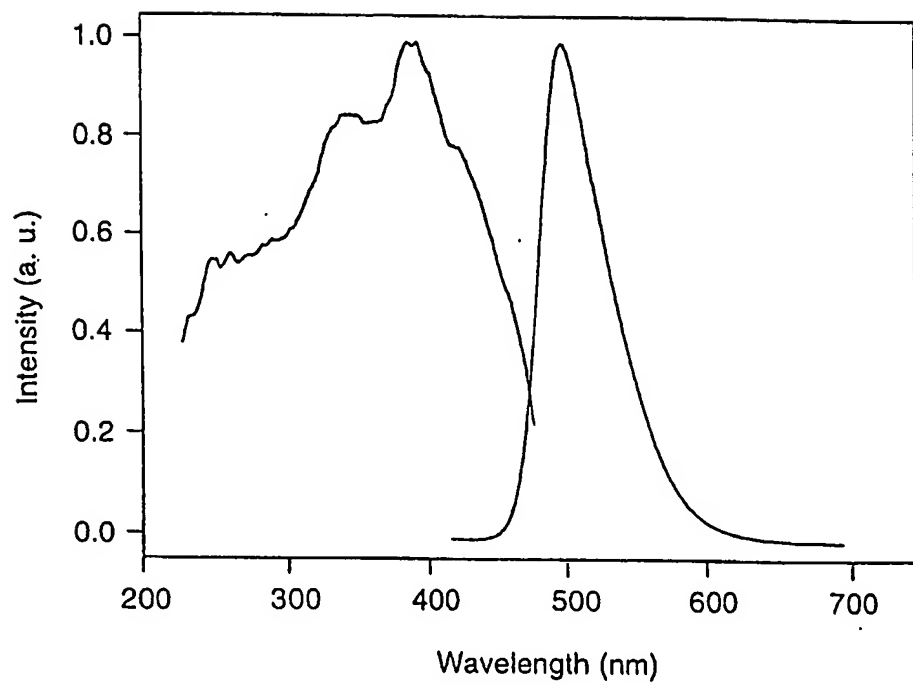


FIG. 5